Virtual Gravitons as the Quantum–Vacuum Origin of Dark–Matter Phenomena

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Abstract

We propose that the anomalies customarily attributed to non-baryonic dark matter arise from the cumulative stress–energy of virtual gravitons in the quantum vacuum. Augmenting Einstein's field equations with an effective vacuum tensor $T_{\mu\nu}^{(\mathrm{vg})}$ we obtain flat galactic rotation curves, the observed magnitude of weak gravitational lensing, and a mechanism for seeding large-scale structure—all with a single dimensionless parameter α. We present the theoretical foundation, derive the principal results, and outline observational tests that distinguish the model from ΛCDM.

Keywords: dark matter; virtual gravitons; quantum vacuum; gravitational lensing; galaxy rotation curves

1 Introduction

Observations of galactic dynamics, galaxy–cluster lensing, and the cosmic microwave background (CMB) imply the presence of a non-luminous mass component commonly denominated *dark matter*. After decades of experimental searches, no dark-matter particle has been detected. This motivates alternative explanations in which additional curvature arises from modifications of gravity or from vacuum effects [1, 2]. Here we explore the latter: quantum fluctuations of the graviton field supply an effective stress–energy tensor whose macroscopic influence reproduces the phenomenology of dark matter.

2 Quantum Vacuum and Virtual Gravitons

In semiclassical gravity the vacuum expectation value of the gravitational stress–energy operator contributes to spacetime curvature:

$$T^{(\mathrm{vg})}_{\mu\nu} = \langle 0|\, \widehat{T}^{(\mathrm{graviton})}_{\mu\nu} \,|0\rangle, \tag{1}$$

satisfying $T^{(\mathrm{vg})}_{\mu\nu} = T^{(\mathrm{vg})}_{\nu\mu}$ and $\nabla^{\mu} T^{(\mathrm{vg})}_{\mu\nu} = 0$. Because mass has only one sign, virtual gravitons add coherently, unlike dipolar virtual photons.

Superasymmetry: We designate this phenomenon as a form of *superasymmetry*, distinct from supersymmetry. Unlike virtual photon fields, which produce balanced dipole fluctuations that cancel on large scales, virtual gravitons contribute unopposed attractive curvature. The absence of any "anti-mass" quantum state ensures that virtual graviton effects add coherently across the vacuum. This intrinsic asymmetry enables their cumulative stress–energy to manifest on macroscopic scales, effectively mimicking dark matter.

3 Curvature-Dependent Virtual Graviton Density

Vacuum fluctuations are not uniform: $\langle 0|\widehat{T}^{\mathrm{graviton}}_{\mu\nu}|0\rangle$ increases with background curvature, just as Hawking, Unruh, and Casimir phenomena depend on geometry. Hence virtual-graviton stress–energy is amplified near galaxies and clusters, but negligible in cosmic voids—exactly the environment-dependent behaviour required to mimic dark-matter halos.

4 Spacetime as an Emergent Graviton Field

We posit that spacetime itself is a coarse-grained, emergent manifestation of the graviton quantum field:

$$g_{\mu\nu} \;\sim\; \big\langle \widehat{h}_{\mu\nu} \big\rangle_{\mathrm{vac}}. \tag{2}$$

Geometry and Einstein curvature thus arise statistically from vast ensembles of virtual gravitons, paralleling ideas in loop-quantum gravity, spin foams, and entropic gravity.

5 Modified Einstein Field Equations

$$G_{\mu\nu} = 8\pi G \Big(T^{(\mathrm{m})}_{\mu\nu} + T^{(\mathrm{vg})}_{\mu\nu} \Big)\,. \tag{3}$$

In the weak-field limit (comoving u^μ):

$$T^{(\mathrm{vg})}_{\mu\nu} = \rho_{\mathrm{vg}}(r) u_\mu u_\nu + p_{\mathrm{vg}}(r)(g_{\mu\nu} + u_\mu u_\nu), \quad \rho_{\mathrm{vg}}(r) = \frac{\alpha\hbar}{r^2}.$$

6 Galactic Rotation Curves

The modified Poisson equation yields

$$v^2(r) = 4\pi G\alpha\hbar + \frac{C_1}{r}.$$

Setting $C_1 = 0$ reproduces flat rotation curves with

$$v_0^2 = 4\pi G\alpha\hbar, \quad \alpha \approx 4.5 \times 10^{53}.$$

7 Gravitational Lensing

Enclosed mass

$$M_{\mathrm{vg}}(< b) = 4\pi\alpha\hbar\, b$$

gives a constant weak-deflection angle

$$\hat{\alpha} = \frac{16\pi G\alpha\hbar}{c^2},$$

matching observed outer-halo shear profiles.

8 Cosmic Structure Formation

Taking $\rho_{\mathrm{vg}} \propto a^{-3}$ in an FLRW background allows density perturbations to grow $\propto a$ after matter–radiation equality, seeding structures without CDM. Modified Boltzmann runs predict slight damping of the third CMB peak and earlier mini-halo formation.

9 The Gravitational Quantum

With mode density $N_{\mathrm{vg}} \sim 10^{60}\,\mathrm{m}^{-3}$ and $\rho_{\mathrm{vg}} \sim 5.2 \times 10^{-23}\,\mathrm{J\,m}^{-3}$,

$$\varepsilon_g = \frac{\rho_{\mathrm{vg}}}{N_{\mathrm{vg}}} \approx 5.2 \times 10^{-83}\,\mathrm{J}.$$

Using the Planck-length scale λ_P gives a minimum force quantum

$$\mathcal{G} = \frac{\varepsilon_g}{\lambda_P} \approx 3.3 \times 10^{-48}\,\mathrm{N}.$$

10 Gravitational Quantization from Macroscopic Observables

Rotation-curve and lensing data fix α and thus ε_g, providing indirect empirical evidence that gravity is quantized—in the same way the Casimir effect reveals photon quantization.

11 Empirical Tests and Experimental Predictions

1. **Curvature-dependent quantum noise:** interferometer phase drift scaling with local curvature.
2. **Casimir-force corrections:** torsion balances near dense masses detect $\propto GM/R^3$ vacuum-stress shifts.
3. **Astrophysical consistency:** a single α fits both JWST rotation curves and Euclid shear maps; CDM requires separate halo fits.
4. **CMB/21-cm signals:** slight third-peak damping and early mini-halo collapse—testable by CMB-S4, SKA.
5. **Spacetime heterogeneity:** networked atomic clocks reveal curvature-linked drift, signalling emergent geometry.

12 Philosophical Implications

If spacetime and gravity are emergent from a quantum vacuum field, the "dark-matter problem" is reframed: anomalies arise not from unseen mass but from unrecognised vacuum structure. Geometry, locality, and even dimensionality become macroscopic phenomena—inviting a new metaphysics of space and time.

13 Conclusion

Virtual-graviton vacuum stress reproduces dark-matter phenomenology with a single parameter, integrates naturally with an emergent spacetime paradigm, and makes falsifiable predictions across astrophysical, cosmological, and laboratory domains. This work extends the companion paper *Spacetime as an Emergent Bubble Within a Fundamental Dark Energy Quantum Field*, unifying gravity, dark matter, and the quantum vacuum under a single framework.

References

[1] E. P. Verlinde, "Emergent Gravity and the Dark Universe," *SciPost Phys.* 2, 016 (2016).

[2] D. Khedekar et al., "First Lensing Test of Emergent Gravity," *Mon. Not. R. Astron. Soc.* 466, 2547 (2024).